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Thesis

The Japanese Beetle

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INTRODUCTION

In 1916 E. L. Dickerson and H. B. Weiss of New Jersey Department of Agriculture collected a few beetles near Riverton, New Jersey, which at that time, proved to be of an unknown species. They were later identified by E. A. Schwartz of the Bureau of Entomology to be the same as a species locally common on the island of Japan. Only twelve of the species, which eventually became known as the Japanese beetle (*Popillia japonica* Newman), were found in Riverton that year. From the time of its discovery it spread in New Jersey and Pennsylvania, until at the close of the summer of 1923, the total infested area amounted to 2,442 square miles.

At that time little was known concerning the habits of this insect in Japan, there being no information to show whether the insect would in time prove to be a serious pest. Attempts to exterminate the insect were made by spraying food plants with applications of arsenical sprays and by treating the sod-lands with cyanide. These measures may have served as a temporary check on the distribution of the insect, but its spread continued until eradication or extermination became practically impossible. Practical measures of artificial control helped to prevent the spread by restricting the movements of products likely to carry the insect, and the importation of parasites and diseases found in its native home, which were believed to play an important part in the natural control of the Japanese beetle.

Its successful establishment is due to the fact that the adult is almost omnivorous attacking many crops, such as fruit and foliage of the apple and peach, cherry, grape, beans, clover, alfalfa and sweet corn; also various shade and ornamental trees, shrubs, and herbaceous plants. The insects are strong fliers and are very active on warm days; its normal spread from year to year being uniform. The beetle has increased in almost unbelievable numbers due to scarcity of natural enemies. The climatological, ecological and cultural conditions in infested areas have been remarkably suitable for its developement. We now have good evidence that this insect is firmly established in the United States. However, by observation and experience it has been shown that the beetle is being brought under control in the area where it has occurred for the greatest length of time.

DISTRIBUTION

Of the subtribe Popilliiana, which is comprised of two-hundred and sixty-four known species, two hundred and nineteen belong to the genus Popillia. The species are distributed throughout the Philippine Islands, Java, Formosa, Sumatra, and islands included in the Malay Archipelago. They are also found in abundance throughout Cochin China, Siam, Japan, Eastern China, Bengal, eastern and northern India, Nepal, Assam, and western China. Seventy-nine species have been recorded in India. One species occurs in Rumania, one in Turkey and two in the Crimean region of Russia. A large number of species have been recorded in east Africa, Abyssinia, and the Congo, with a few species occurring as far south as the Cape Colony district. Other species have also been recorded in the countries on the

west coast of Africa, especially Kamerun, Nigeria, Ashanti, Togo, Sierra Leone, Senegal, and French Sudan. Three species are found in Algeria, two in Tripoli, and five have been reported from Egypt. Except where they have been introduced, no representatives of this subtribe are found in North America or South America. These insects, as a group, are tropical in their occurrance, since the majority of the species are distributed between the Equator and twenty degrees north and south latitude. The insects found in Japan and Manchuria occur between fifty and fifty-five degrees north latitude. In northern India most of the species are found between twenty-eight and thirty-eight north latitude and at elevations of 1,500 to 7,500 feet. Several species are of great economic importance in various countries, particularly Popillia hilaris Kraatz, which causes considerable injury to cotton in British East Africa. Popillia biguttata Weil has been recorded as causes injury to tea, coffee, and other plants in Java.

The native home of Popillia japonica Newman is the main islands of Japan. Its occurance in continental Asia has not been definitely determined. P. atrocoerulea Bates occurs in northern China and Korea and has been confused with P. japonica by some entomologists. P. japonica, variety plectipennis, which was described from Japan is identical with the plectipennis, in Borneo.

On the Japanese islands of Kyushiu and Shikoku the Japanese beetle is common but not abundant, and in Hondo, from Yokohama northward, the beetles are usually more numerous. In Saitama, Tachiga, and Fukushima Kens, where the soybean is one of the principal crops, the species is at times numerous enough to cause some damage. Farther north, at Morioka, the

infestation is often heavy, but the preference for certain weeds, particularly the itadori (Polygonum reynoutria), which grows wild along the roadsides, has prevented serious damage to crops of economic importance. The beetles occur generally throughout the island of Hokkaido. Here, as in the northern portion of Hondo, the crops grown are similar to those in our North-Central States. Damage to crops by the beetles sometimes occurs in these regions.

Native parasites, lack of large areas suitable for its reproduction and development, and an insufficient supply of food, all contribute to check the propagation of the Japanese beetle in Japan. On the other hand, areas which favor development of larvae are intensely cultivated, and there is little opportunity for the species to reproduce in large numbers. Upon its introduction into New Jersey the beetle found favorable conditions for development, and food in abundance. These favorable factors together with the absence of the parasites have allowed this pest to increase to a point where its injuries are of grave economic importance.

INTRODUCTION AND SPREAD

Speculation as to the way in which the beetle was introduced into this country has lead to the general belief that the grub stage of the insect was present in soil surrounding plants imported from Japan about 1912. The Federal Foreign Plant Quarantine regulations permitted plants surrounded with soil to be admitted unconditionally until 1919. The Federal Foreign Plant Quarantine No. 37, which became effective in 1919, prohibited the introduction of soil, and drastically restricted plant importations into the country.

Since 1916 the beetle has spread steadily until at the end of the summer of 1923 it had infested an area of about 2500 square miles in New Jersey and Pennsylvania. The following figures show the spread of the insect from 1916 to 1929 involving the following area increases in square miles.

	New Jersey	Pennsylvania	Delaware
1916	?		
1917	0.5		
1918	1.1		
1919	3.0		
1920	20.0	0.8	
1921	60.0	6.0	
1922	100.0	20.0	
1923	150.0	30.0	
1924	225.0	45.0	
1925	300.0	70.0	
1926	410.0	100.0	
1927	620.0	170.0	
1928	1000.0	270.0	
1929	1500.0	400.0	1.

Inasmuch as the regions now occupied by the Japanese beetle offer excellent conditions for its growth and rapid multiplication, it is of interest to describe briefly the physiography of the infested areas. The beetle is now found in the central and western parts of New Jersey and in eastern Pennsylvania, and the regions into which there is danger of its spreading include part of the Piedmont Plateau and the Coastal Plain.

The Piedmont Plateau is one of relative uniformity in its faunal and floral features, therefore subdivisions of a biological nature are not readily distinguishable. In contrast to this, the Coastal Plain region, has marked differences in its faunal and floral features. Generally speaking, the Piedmont Plateau is a district of considerable relief, the surface of a rolling type, gradual on the upland, quite broken in the wider valleys, and precipitous near the streams. Quite different from this is the Coastal Plain, of low elevation,

general relief, and poorly drained interior. Soils of fine texture predominate and they are of the highest agricultural value. In the interior, especially in the section known as the Pine Barrens, coarse siliceous soils occur everywhere.

The Japanese beetle was introduced into the central portion of "the middle district" of the New Jersey Coastal Plain region, but at the close of the season of 1923 it had spread across the Coastal Plain into the Piedmont Plateau region in Pennsylvania in the west and extended its range across the Pine Barrens to the Atlantic coast and in the east.

Favorable food plants and soil requirements have promoted the rapid spread of the Japanese beetle. Although capable of feeding on cultivated plants the insect prefers hydrophytes or mesophytes. It is therefore natural to assume that their spread is favored in regions where hydrophytic and mesophytic vegetation is found in abundance; likewise it is reasonable to believe that the advance of the beetle would be retarded wherever xerophytic conditions prevail. The food requirements of the japanese beetle grubs are found in soils with a good covering of herbaceous vegetation, especially where there is a permanent or semi-permanent sod. The soil must be of such a texture, moisture condition and chemical reaction as to permit growth of vegetation furnishing food to the beetle and its larva. Such vegetation is usually of a mesophytic character. It is safe to say that soils that do not allow a too rapid drainage of water favor the development of the Japanese beetle, whereas porous soils including coarse sands and gravel, also impervious types such as stiff clays, are detrimental to the development of the species. A moderate amount of moisture is essential for larval growth. On the other

hand, a decided lack of moisture, or an excessive amount of moisture inhibits successful development. From such observations we can safely conclude that the Japanese beetle does not establish itself successfully in dry regions or in swamps or marshes, but does thrive in moist soils suited to agricultural purposes.

The soils infested with the Japanese beetle when studied from the chemical standpoint are found to be neutral in reaction or at most slightly acid. Such soils furnish the beetles with their favorite type of vegetation. From the environmental standpoint it can be said that open campestral country, with plenty of permanent sod-lands and weedy areas, which support a rich growth of hydrophytic and mesophytic vegetation is highly favorable to the rapid spread and development of the Japanese beetle.

ECONOMIC STATUS OF THE INSECT

The ravages of the pest are responsible for greatly increased costs in commercial fruit growing and other horticultural pursuits. Apples require extra spraying even after codling moth sprays have been regularly applied. Extra sprays of milk and lime, and lime and lead arsenate respectively are required by early and late peaches. Cherry trees require a coated lead arsenate spray after the fruit has been picked. Raspberry and blackberry plantations maturing fruit throughout the beetle-feeding period can not be protected by spraying. Production of sweet corn is also unsatisfactory. Susceptible shade trees and ornamentals require a coated lead arsenate spray. Approximately 55,000 pounds of coated lead arsenate, preparing 687,500 gallons of spray material, were used in protective work in 1929 in New Jersey. Nurserymen

have a slight added expense and inconvenience in complying with quarantine regulations. Golf clubs have been obliged to treat with lead arsenate both fairways and greens because of grub damage.

In New Jersey approximately two hundred species of plants furnished food for the beetle. Practically all the crops of economic importance are included in this number, the most important of which are the apple, quince, peach, sweet cherry, plum, grape, blackberry, clover, soybean and corn. Few of the shade trees attacked include linden, birch, oak, elm, sassafras, horse chestnut, and willow; ornamental shrubs, particularly althaea and rose flowers of all kinds and several kinds of weeds are also attacked.*

The Japanese beetle (Popillia japonica) after being studied for four years in Japan has not been regarded as a serious pest, but at times it has done considerable damage to soybean plants. During the summer of 1921 at Koiwai, feeding by the beetle was chiefly upon Polygonum reynoutri which grew along the roadside bordering the breeding ground, and immediately joining was a large field of soybeans. The Polygonum foliage was almost skeletonized, but hardly a single individual was found in the adjoining soybean field. At Koiwai also, where considerable corn is grown, there is no damage to the silks or the green corn. However, at Riverton, corn silk and green corn are favorite foods. Likewise wistaria at Yokohama is much fed upon by Popillia, yet wistaria at Sapporo is rarely touched. These points illustrate a common

*See pages 9-11 in department circular #363 issued March, 1926 by the U.S.D.A. for a list of the food plants of the Japanese beetle in N. J.

JAPANESE BEETLE (*Popillia Japonica*)

The beetle deposits its egg in the soil. The larvæ, or grubs, hatching from them, feed on grass roots and decaying vegetable matter until autumn, when they become full grown. No feeding occurs during the winter, but in the spring the grubs feed for about a month before transforming to the tan-colored pupæ. These change to the adults, or beetles, and emerge about the middle of June. The beetles cause damage by feeding on foliage and fruit. The grubs cause serious injury to sod lands through the damage which they inflict on the roots of grasses. Stages in soil, and inset, somewhat enlarged; beetles on foilage and fruit much reduced

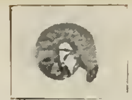
feeding habit, namely, that the favorite food plants of one district, although present in another, are often not fed upon by the beetles.*

Injury of economic importance is chiefly done by the adult beetles upon orchard trees. Because the larvae of the Japanese beetle are found in the soil and feed on the roots of the living plants, it is difficult to judge the result of damage to the several crops and plants of economic importance which they may attack. Pastures, lawns and golf courses suffer more or less injury from the larvae. Where the infestation of larvae is heavy, injury upon beans and other vegetable crops, as well as ornamental plants is often very noticeable. Strawberry beds are sometimes destroyed, due to the root feeding habits of the larvae. If the infestation of larvae is more than two hundred to the square yard, injuries to the grass may be noticed especially if dry weather occurs during the latter part of May or June.

DESCRIPTION AND BIOLOGICAL FEATURES

The Japanese beetle egg when laid is spherical in shape, about one-sixteenth of an inch in diameter and dull white in color. Under magnification the surface appears finely punctate, the tiny punctures being somewhat hexagonal in shape. There is considerable variation in the size and shape of the eggs, particularly during the first four or five days after they have been deposited. It has been observed that a few of the eggs are almost perfect spheroids; others show considerable difference between the two diameters. The eggs do not increase in size until six or seven days after they have been laid.

*See pages 47 & 48 in Bulletin 1429, U.S.D.A., Washington, D. C., issued January 1927, for a complete list of food plants of the Japanese beetle in Japan.



Average Size of Grub

FIGURE 4.—The Japanese beetle grub enlarged eight times

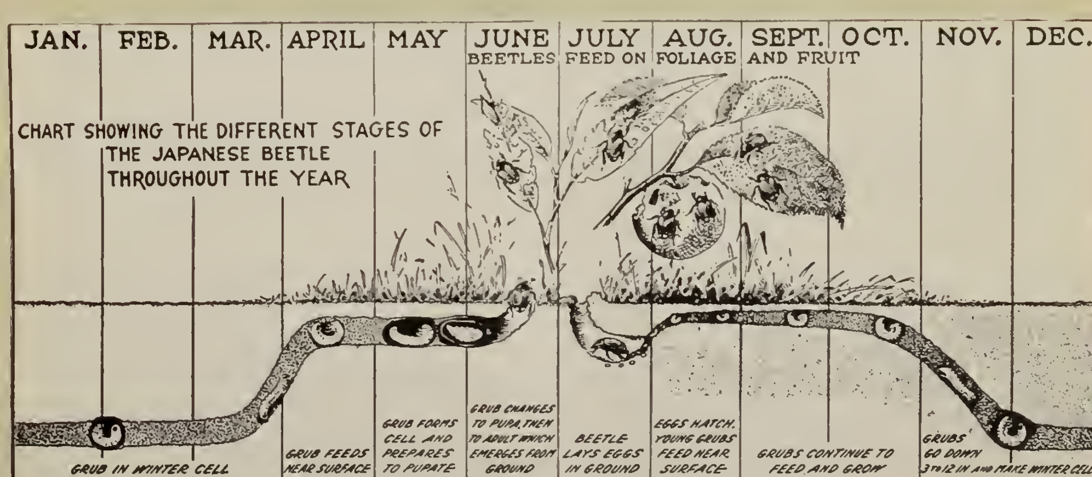


FIGURE 2.—Diagrammatic presentation of the annual Japanese beetle life cycle.
(Courtesy of Japanese Beetle Research Laboratory).

At this time they begin to enlarge and become more spherical in shape. By the seventh day the embryo larva can be seen through the shell, and by the eighth or ninth day the eggs are nearly twice as large as they were as when deposited by the female beetle. The average incubation period is from fourteen to twenty-one days with reported extremes at nine and forty days. Observations indicate that the percentage of fertility is quite high. The absence of light, and high humidity, conditions which most soils provide, are important factors in normal egg development. It is entirely likely that many eggs laid in sandy soils never survive because of the extreme drying to which they are subjected. These eggs give rise to the grub or larval stage of the insect.

The hatching of the egg yields a small white grub or larva about one-sixteenth of an inch long. Anatomically, this larva consists of a head, three thoracic segments and ten abdominal segments. The head contains the mouth parts composed of two lips, usually visible, and a pair of mandibles or jaws, immediately within, and laterally attached. A pair of legs are fastened to each of the thoracic segments. The anal plate of the last abdominal segment has a characteristic arrangement of hairs, these serving as the basis for identification. Air necessary for respiration is taken into the body through small openings or spiracles on the sides of each of the body segments.

The larval stage of the Japanese beetle may be divided into three sub-stages; namely, first, second and third instar. These instar periods are terminated by a molting or shedding of the skin carried through the instar just ended. The first instar commences at the time the larva is hatched and contin-

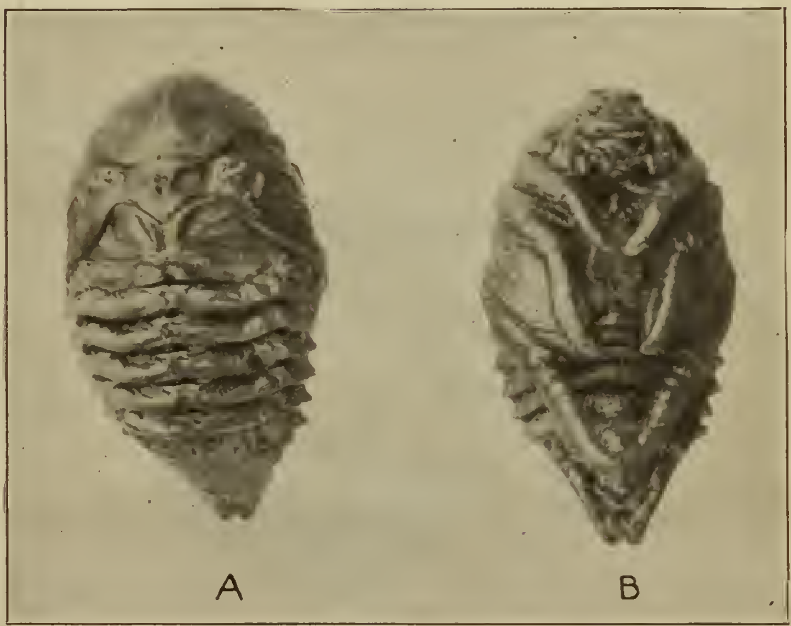


FIG. 4.—A, Dorsal, and B, ventral, views of pupa of the Japanese beetle. Greatly enlarged

ues throughout this period. The first instar period is terminated after a short (1 day) quiescent period with the shedding of the old skin.

The second instar period continues the growth of the larva, this period lasting usually from 15 to 20 days. However, many larvae hatched late in the season probably pass the winter in the second instar. Again the old skin is shed.

The third instar period is the usual one of hibernation. The larvae burrow to a deeper level (5 to 12 inches) to avoid the alternate freezing and thawing. This stage usually persists until early June of the following year. During the latter days of the third instar pupal formation begins within the body of the larva. Approaching the close of the third instar period the larva prepares an oval soil cavity about four inches below the surface into which the pupa is to be expelled, this taking place at the close of the period with the splitting of the larval skin.

Of these three larval stages several generalities can be established. Vertical movement in the soil is seldom deeper than ten inches. Lateral movement, believed to be not more than two feet, is probably influenced by the abundance of food materials. The thoracic segments have a firm fleshy structure, the abdominal segments, flabby, black and watery. The color of the abdominal segments is partly due to the considerable proportion of the soil ingested into the larval body. Differentiation of sex has not been demonstrated. Each of the stages can be sustained with either humus (decaying organic matter) or living organic matter (roots, etc.). During the molting, the larval skin splits along the entire back.

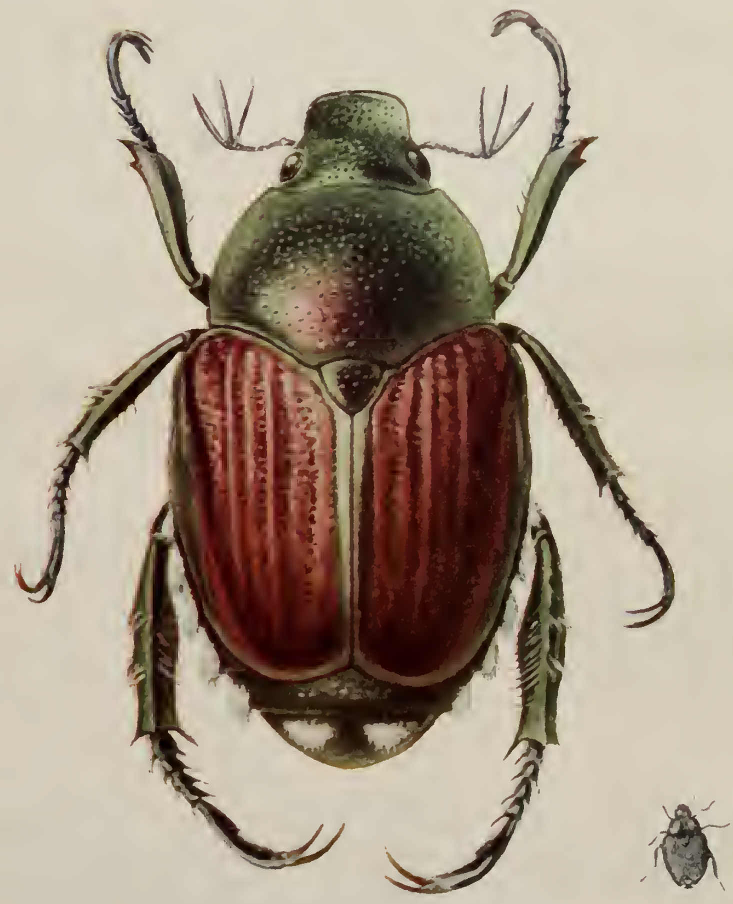


FIGURE 3.—THE JAPANESE BEETLE

The smaller figure shows its natural size. The head and thorax are shining bronze green in color, with the wing covers tan or brownish, tinged with green on the edges. Along the sides of the abdomen are white spots, made of tufts of white hairs, with two very distinct white spots at the tip of the abdomen, below the wing covers. If these white spots are present, the insect is the Japanese beetle.

The pupa of the Japanese beetle is a developmental stage characterized by inactivity, and internal changes of a very phenomenal nature. The pupa enclosed in a cuticular skin begins this stage with only the rudiments of the larval body. The entire insect body assumes a heavy chitinous covering, of a metallic lustre. The head is now supplied with heavier lips and stronger mandibles. Two antennae are projected from the head. The thorax while still consisting of three segments is somewhat widened. The legs continue to be supported by the thoracic segments. A pair of wing covers and a pair of wings are attached to the body at the junction of the last thoracic segment and the first abdominal segment. The abdominal segments, only six of which are visible, enclose a very much abbreviated digestive system and the reproductive organs. Sex differentiation is now established. The pupal stage lasts from seven to twenty days, after which the cuticular skin is ruptured, freeing the mature adult. The beetle then finds its way to the surface of the soil for emergence.

The adult Japanese beetle is a beautiful and brightly colored insect, varying in length from five-sixteenths to seven-sixteenths inch and in width from three-sixteenths to nine-thirty-seconds inch. It is broadly oval in shape, moderately convex, and shining. The upper surface is somewhat flattened, without pubescence, hairs, or scales. The color is bright metallic green, except the greater part of the wing covers, which are coppery brown. The elytra do not cover the abdomen, but expose a row of five lateral and two posterior marginal spots composed of white hairs. The under surface of the body is clothed with short, grayish hairs. The head is thickly and coarsely punctured; the striae of thewing cover

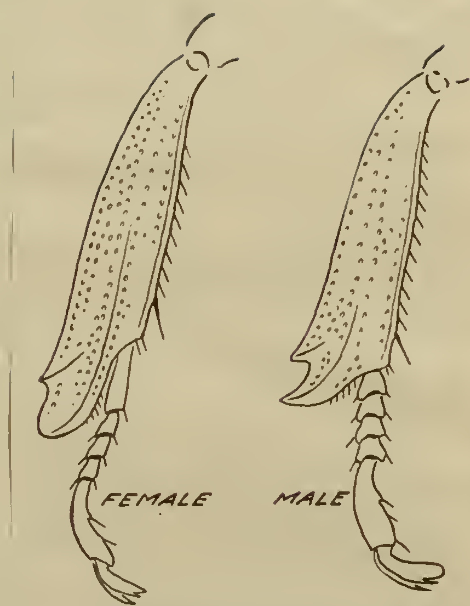


Fig. 5.—Fore-tibiæ and tarsi of the Japanese beetle, greatly enlarged, showing difference in structure between male and female beetles. It is by the character of the spur on the outer end of the tibia that the sexes are most easily distinguished

are imperfect, terminating considerably below the apex of the elytron. The legs are of a dark, metallic, coppery green color, varying in tint in different positions. The sexes are most easily distinguished by slight differences in the form of the tibia and tarsus.

LIFE HISTORY OF POPILLIA JAPONICA IN JAPAN

The varying life cycle of Popillia as it occurs in Japan has an important bearing on certain of its parasites. When this is compared with the life cycle in the United States it will be seen that further conditions will undoubtedly arise which will have an important bearing on the parasite-introduction problem, and it is therefore important that these points should be further discussed.

Popillia japonica is found on all of the main islands of Japan, but does not extend to the Asiatic mainland. It is most abundant in the northern half of Honshu and all of Hokkaido in the areas where grasslands occur. This northern habitat corresponds somewhat in climate to that of New Jersey and Pennsylvania. Nowhere in Japan is it a pest of much economic importance.

At Yokohama(lat. 35.5° N.) Popillia is common but not abundant enough to be of any importance as a plant pest. Here the first beetles of the season appear as early as May 28, the maximum numbers being found in the field about June 20, after which date a gradual decline takes place and by July 25 only a very few stragglers are found. In this locality one complete generation occurs each year, there being no evidence of larvae going over a second season; in fact all reach the third instar by mid-September of the year in

which the eggs are laid.

At Koiwai (lat. 39.5° N., altitude 1,500 feet), a small village about 10 miles from Morioka and 300 miles north of Yokohama, the climate is considerably colder than at the latter place, the growing season being confined to June, July, and August. Because of the grass and meadow lands here Popillia is more abundant than southward, although it is not an economic pest. The first beetles of the season appear about July 1, increasing rapidly to maximum numbers by July 24, after which the decline is gradual through August, and by September 10 only a few are left. Here approximately 25 to 30 percent of the beetles undergo a two-year cycle. This condition seems constant in northern Honshu.

At Sapporo (lat. 43° N.), on the island of Hokkaido, and about 520 miles north of Yokohama, Popillia is more abundant than elsewhere in Japan, perhaps because of the presence of extensive grass and meadow lands which afford undisturbed breeding grounds. It is said that at times the adults occur in such numbers as to cause damage to the foliage of the soybean, although in four years' observations no material damage to any economic crop was noted.

In this region Popillia has largely a two-year life cycle with about 75 percent of the adults emerging in alternate years. Thus 1920 and 1922 were years of minimum emergence, comprising about 25 percent of the beetle fauna. During these years the first adults appeared about July 5, the maximum numbers occurring about July 22, followed by a rapid decline and the disappearance of the beetles by the first week in August. This latter condition is due to the parasitism of the adults by <u>Centeter cinerea</u>. In the years of greatest

abundance (1921 and 1923) the first beetles appeared about July 5 also, and reached the maximum by the end of the month. The decline was gradual through August and by early September all had disappeared.

In the years of adult abundance virtually all larvae develop into adults, only a fraction of 1 per cent of the total number remaining in the larval stage by the end of July. These doubtless comprise two-year cycle grubs which originated from the 25 per cent of one-year beetles. It is also presumed that a fraction of the progeny of the two-year beetles may revert to the one-year cycle. During the periods of larval scarcity it is impossible to obtain sufficient numbers for experimental purposes.

As contrasted with the life cycle of Popillia at Sapporo and Koiwai, Japan, that in the United States in the infested area of New Jersey is as far as known entirely of one year, corresponding in this respect to the condition existing at Yokohama. At Riverton the first beetles issue in numbers in mid-June, and the maximum emergence is reached from July 10 to 20. From the end of July or mid-August, according to the season, the decline in numbers takes place, coming to a close in mid-September.

THE HABITS OF THE INSECT

After transforming to the adult the beetle remains in the pupal cell from 2 to 14 days before coming out of the ground. There is considerable variation in the size of the adult Japanese beetles. As a rule the females are larger than the males. The size of the larva does not necessarily indicate the size of the adult which may develop from it. The size of the larva,

is dependent on its food supply. After emerging from the ground the beetles usually climb on various low-growing plants, and if the weather is clear remain for a few hours without feeding until they are thoroughly hardened. In many cases, they have been observed copulating, and in some cases the females have returned to the soil and deposited fertile eggs before any food was taken.

Experiments conducted relative to the length of life of the beetles indicate that the male beetles collected upon emergence in the field and brought to the laboratory lived for an average of 46 days. Female beetles collected under the same conditions lived for 44 days. It was found that in the case of beetles which were reared from larvae kept in cages in the insectary the males lived for an average of 34.25 days and the females for 37.94 days. To learn how long the beetles would live without food, 100 females and 100 males reared from larvae in cages were kept continously without food until they died. The average age for male beetles was 7.25 days; for females, 8.50 days. Copulation occurred normally and the females laid the usual number of fertile eggs.

In a majority of cases the females enter the soil late in the afternoon and deposit one to three or four eggs during the night. Some beetles have been found to remain three or four days in the soil. In many cases, however, eggs are laid every third or fourth night, and the egg-laying period extends over three or four weeks. During the morning the beetles concentrate on low-growing plants, such as smartweed and beans. As the heat increases during the day they become more active and disperse to the taller plants until early in the afternoon, when they are abundant on the tallest elms, oaks, and maples.

After 3 p. m. their flight is toward the ground and the lower-growing plants. One sex is as likely as the other to begin a new infestation, provided there are equal numbers of both sexes flying at the time. Hourly and half-hourly collections from several food plants showed that the proportion of females to males was highest between 12 o'clock noon and 2 p. m. and was lowest between 6 p. m. and 6 a. m. The most marked difference in the proportion of the sexes was noted on the taller plants at the different times, whereas on the low-growing species such as smartweed the least difference was observed. A proportion of the females leaving the taller trees may not enter the soil, but remain on low weeds during the night.

There is a general increase in the activity of the beetles during the day until 2 or 3 p. m.; after this time their activity decreases until dark when flight ceases.

There is a distinct movement of the males toward those plants on which the females are feeding. On clear days, between 8 and 9 a. m., numerous males can be observed flying low over the ground in search of emerging females. During the early part of the day this tends to concentrate the beetles on low-growing plants, such as smartweed, beans, and various weeds. In 1922 this habit was particularly noticeable on the golf course at Riverton. On clear days the beetles' flight commenced between the hours of 8 and 8.30 a. am., and the first beetles found on the wing were invariably males. As the females would issue from the ground the males would alight and attempt copulation before the females had opportunity to take flight. This resulted in a large number of males alighting on and near the female, and in their attempts at copulation the congregated beetles resembled balls. From one of these

masses with only 1 female present 198 males have been collected. It was observed that in alighting the males always approached the female against the wind, apparently being attracted by the odor, and when they alighted on the ground it was usually from 4 to 6 inches on the leeward side of the female, which they approached by crawling along the ground. As the males drew in rapidly this resulted in a trail of male beetles several inches long extending from the ball which was forming about the female. As the wind would shift slightly the direction of the trail of males would change within two or three minutes, so that the trail of beetles was always directly opposite to the direction in which the wind was blowing. Apparently copulation rarely took place when so many males were present. In only one instance upon examination of several hundred of these balls was the female found to be in the act of copulation. The habit of balling usually ceases about midday, not to recur again until the following morning. In an area of 25 square yards on a golf course 78 balls of the beetles were observed at one time, each ball being composed of a single female and from 25 to 200 male beetles.

The feeding habits of the larvae have been observed many times, both in the laboratory and in the field, and have been found to differ somewhat from those of certain of our native species. The larva forms a cell in the soil slightly larger than its body and feeds on the fine rootlets at the top and bottom of the cell. In feeding, the grubs usually follow the course of the rootlets until these are consumed before attacking others, thus preventing injury to grass from being extremely serious. The general movements of the larvae in the soil are vertical, whereas the larvae of the

native Cyclocephala (Ochrosidea immaculata Oliv.) and Anomala (Pachystethus lucicola Fabr.), which are abundant in this region, usually feed and move in a direction parallel with the surface of the ground. During the seasons when the Japanese-beetle larvae are feeding they occur in the soil at depths varying between one-half inch and 3 inches. The depth at which the larvae are found is more uniform for a short time before they descend on the approach of cold weather in the fall, and again during the period preceding pupation.

The larvae are positively thigmotropic and are attracted to living roots, and if these are not available, to stones or sticks or to the bottom and sides of the breeding cages.

Dissections were made of a large series of larvae collected in grass sod, and the contents of the fore part of the alimentary canal were carefully removed. It was found that the material eaten by the insects was composed of small soil particles, fresh plant tissue, and small pieces of plants which were partially decomposed. Analysis of the material eaten by 25 larvae showed it to be composed as follows:

	Grams
Total weight of food collected	21.4134
Dry weight of food collected	15.4769
Ash remaining after ignition	5.0556
Loss from ignition	10.4213

These figures indicate that organic material constitutes about 67.33 per cent by weight of the total material consumed by the larvae.

On examination of the material contained in the fore part of the alimentary canal, the soil particles and pieces of plant tissues were found to be relatively uniform in size. The greatest variation occurred in those tissues which were partially decomposed.

FIGURE 8.—Exposure of Japanese beetle larvae by rolling back an area of dead turf.
(Courtesy Federal Japanese Beetle Laboratory.)

By experiment it was found from 25 larvae approximately 84 per cent by volume of the material eaten was vegetable matter; 64.3 percent of the total amount of material consumed was from the roots of living plants.

A series of experiments was conducted to determine the mortality of the larvae when reared in soils containing varying amounts of organic material. From the data obtained, it is believed that though the larvae may survive in soil a certain length of time without living roots upon which to feed, the presence of the roots is extremely important for their development. This belief has also been borne out by results in the rearing cages, where entire series have died for no apparent reason other than starvation when sod was not added to the soil.

During April and May, 1921, larvae were observed actively feeding on the roots of rye, clover, and several of the pasture grasses. Further observations made in fields of rye disclosed the fact that in nearly all cases the larvae were congregated about the roots of the rye stools. Larvae have also been found feeding on the large taproots of clover, some of which were nearly eaten through between 1 and 2 inches below the crown. The larvae do not confine their attacks to grasses and legumes, since records have been obtained of their feeding on the roots of such plants as iris, peony, gladiolus, arborvitae, small conifers, and other ornamental plants and shrubs, and also on the roots of corn, beans, tomatoes, and other vegetable crops.

The first injuries to grass sod which were noted were found in a pasture in which the larvae numbered between 150 and 200 to the square yard. Areas were injured to such an extent that the sod could be easily rolled up with the fingers/

Many of the plants the roots of which were not entirely eaten off by the grubs were killed by the hot, dry weather prevailing later in the season. Many weeds and coarse-rooted grasses do not show any appreciable effects from the feeding of the larvae, whereas the finer-rooted species, such as bluegrass and redtop, are killed. For this reason it is probable that the most important injury by the larvae will not usually result in the destruction of the sod, but rather in the killing out of the more desirable species of grasses for pasture or hay purposes, and their being replaced by less desirable species.

Golf courses offer particularly favorable situations for the development of the larvae. The Country Club course at Riverton, N. J., has for the past three years been generally infested with the larvae. On an average of a number of diggings less than 50 larvae to each square yard were found in the spring of 1921. During 1922 several of the fairways at the Riverton course had infestations of the larvae varying between 300 and 800 to the square yard, and the sod was so severely injured that in some cases the fairways had to be torn up and reseeded in the fall. In 1923 the infestation in the putting greens was considerably heavier, and in order to save them treatments were made to destroy the larvae. Aside from the direct injury to the grass roots, the playing surface was rendered soft and spongy by the burrowing of the larvae in the soil. It was noticeable that the most severe injury to the grass occurred on the higher portions of the greens and especially about the margins. These would probably be the places which would receive the least water when

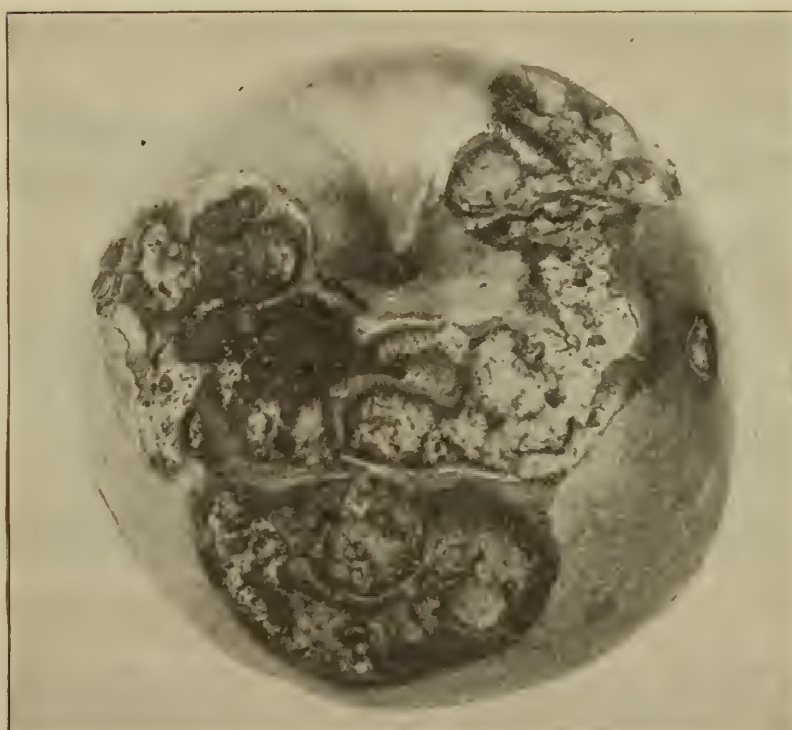


Fig. 19.—Apple injured by the Japanese beetle

the greens were sprinkled. Much of the feeding on the greens was done just below the surface of the ground, the larvae being in most cases between one-half and three-fourths inch beneath.

The Japanese beetle is most conspicuous and injurious in the adult stage by reason of its active habits and the injuries it causes to foliage and fruit. The injury to foliage is most conspicuous and characteristic, being comparable with the eating done by native leaf-chafers. Small plants may be defoliated; on trees the leaves are usually skeletonized, and when severly eaten they turn brown and drop, thus producing the same effect as defoliation. Since the beetles prefer to feed on foliage exposed to the direct rays of the sun, it is not usual for them to defoliate entirely the larger shade and timber trees. Usually they commence to feed on the upper and outer foliage and work downward; by the time one-half or two-thirds of the foliage on the tree in question has been consumed, the beetles will leave and congregate on other plants. If such feeding is continued year after year under the present numerical concentration of the beetles, however, it will result in the destruction of many fine and valuable ornamental trees.

Fruits which ripen early in the season are most subject to the attacks of the beetles. This injury has been noted as being especially severe in apple orchards which were poorly cared for and in which, in consequence of the injuries of the codling-moth larvae and other insects, a large part of the fruit ripened prematurely, and in peach orchards where brown-rot affected much of the fruit.

The beetles are extremely fond of the green corn silk

Fig. 20.—Japanese beetles feeding on peach fruit

Fig. 21.—Japanese beetles feeding on peach fruit, and foliage damaged by the insects

Fig. 16.—Japanese beetles feeding on silk at tip of an ear of field corn

and the developing ear, and cluster at the tip, frequently by dozens, cutting off the green silk close to the husk and feeding on the green developing kernels at the tip of the ear. Frequently ears have been noted on which the grains and husk were eaten for more than half the length of the cob. When the beetles are abundant it is not unusual to find fields of either sweet or field varieties of corn in which from 95 to 100 per cent of the ears are injured by the beetles; from 10 to 15 per cent of these are rendered unfit for market purposes. The injury to the ears is in most respects more serious than that caused by the earworm (Heliothis obsoleta Fab.). It is possible that the cutting off of the green silk from the ears causes an imperfect pollination of the corn. This type of injury also occurs in red clover. It has been noted that the beetles are attracted to the blossoms of red clover, and feed largely on the floral parts. Observations indicate that by feeding in this manner the beetles are capable of preventing fertilization of the blossoms and thus hinder the subsequent production of clover seed.

The degree of infestation of the various food plants is not constant. At times a plant or group of plants may have numerous beetles on them and later observations show that the insects have left them for other food plants. Instances have been noted on peach, smartweed, sassafras, and apple where the plants were heavily infested for awhile and later had very few beetles feeding on them. In some cases the plants in question were not reinfested during the season.

The Japanese beetle may properly be termed "polyphagous" in its food habits, having been recorded as attacking more than 200 species of plants. In the past certain species

more than others have been injured by the beetles. As the beetles do not feed consistently on any one type of plant, a general statement that one particular species is preferred can not be made. Almost no plants, excepting certain conifers, are exempt from attack between June and November when the beetles are present. At times they will be found abundantly on low-growing plants, such as white clover (Trifolium repens), violet (Viola sp.), or galinsoga (Galinsoga sp.), or they may feed on the taller types of shade trees.

The beetles are strongly attracted to ripening fruit, and early apples and peaches may suffer severe injury from the depredations of the insects. So numerous do the beetles become at times that individual fruits, especially where they have prematurely ripened, will be completely covered by a swarming mass of the insects. As many as 278 beetles have been removed from a single apple. It has been noted that the foliage of those varieties which ripen early in the season is more severely injured than is that of the so-called late varieties. It is possible that this may in a measure be caused by some attraction of color or odor of ripening fruit rather than by a preference for the foliage of the early varieties. No apples have been observed to be severely attacked early in the season, and it is only after some of the fruit has partially ripened, either prematurely through disease or otherwise, that the heavy infestations occur on apples. Peaches affected with brown-rot caused by Sclerotinia fructigena (Pers.) Schr. are particularly attractive to the beetles, and these insects may yet cause serious losses by carrying this fungus from diseased to sound fruit.

The Japanese beetles are positively phototropic, and

most of their feeding is done on plants which are exposed to the direct rays of the sun. As a result, the first injury to the foliage of various trees occurs on the outer portions of the top and side branches. Early in the season the beetles rarely feed on the peach leaves borne on new wood. As the season progresses, however, they feed more or less generally on the mature foliage. It is of interest to note that on the majority of their food plants the beetles feed on the upper surfaces of the leaves, while in the case of peaches if there were any preference shown for one side of the leaf or the other the preference would probably be for the under side.

The beetles mate and feed more or less intermittently, and there is a considerable movement of the beetles from plant to plant during the day. A female beetle on a plant will quickly attract many males and, owing to the gregarious habits of this species, other females as well. The males become active and are flying in the morning before the majority of the females have emerged from the soil. During this period the male beetles feed erratically and for short periods on a large variety of plants.

DISPERSION

The beetle is a strong and vigorous flier, being very active when the days are hot. Beetles will fly from tree to tree and from place to place for some distance in search of suitable food. The beetles also fly a considerable distance from the fields where they lay their eggs to the feeding places. Individual beetles emerging from the soil have been followed for more than one-half mile. Early in the season suitable food

for the beetle is plentiful, and probably the beetles do not fly as great distances as they do later, when the preferred food plants are less abundant. Observations made during the summer of 1922 indicate that there is a tendency for the insects to range farther in search of food in the latter part of July and August than in June and early July. Although it is not possible to say definitely what is the greatest distance which individual beetles can fly, experiments have been conducted bearing on this point, during the course of which marked beetles have been recovered at least a mile and a quarter away from the point of releasement. It is not supposed that this distance was covered in one single flight, but more probably in a series of flights. The beetles normally fly against the wind, and very little flight occurs when high winds are blowing. This fact tends to account for the rather uniform rate of dispersion from the infested to the uninfested territory year by year.

Winds and storms probably play some part in the dispersion of the insects. After periods of heavy rains beetles have been observed floating down streams on pieces of wood and other debris carried into the stream by the excess water. Undoubtedly beetles can be carried for some distance in this way. Individual beetles have been picked out of the water of the Delaware River at a distance of several hundred yards from the shore line where it flows through the infested territory. Experiments have shown that the beetles are quite able to float in water with the current unless seized by fish or birds, and possibly they have been carried some distance in this manner, especially along the smaller streams flowing through

the infested territory.

It has been found that the beetles are capable of deriving food to a greater or less extent from a variety of our forest trees, although their well-known heliotropic reactions tend to make them resort to more open and brilliantly illuminated areas and to avoid dark and shady situations, such as would be encountered in heavily wooded sections. It is probable, therefore, that the spread of the beetles will be more rapid in open country, where suitable food plants are abundant, than in heavily forested regions.

The movement of human beings on foot in and through heavily infested fields may also result in the local dispersion of the insect. For example, beetles have been removed from the clothing of men working in infested orchards after they have left the orchard; beetles have also been removed from the clothing of pedestrians walking along the roads and paths, or through fields, among the heavily infested orchards.

Artificial dispersion over long distances is most likely to result from the shipment of infested nursey stock. All evidence at hand seems to show beyond reasonable doubt that the original infestation in this country resulted from the importation of iris or azalea stock from Japan with the soil about the roots infested with the larvae of the insect. Several similar cases have come to the attention of the reseachers, where imported stock of this character, upon examination, has been found to carry living larvae of Anomala or other related groups.

Experience with nurseries located in the beetle-infested area has shown that stock commonly shipped with soil around the roots, such as potted stock, and the various conifers, can

very easily carry living larvae in the soil and matted roots to any distance over which the stock itself can be safely shipped.

Stringent quarantine regulations affecting the shipment of nursery stock from infested territory have been enforced for several years, and are now being enforced by the quarantine division of the Japanese beetle laboratory staff; so far as is now known these regulations have been effective in preventing further dispersion through this means.

NATURAL CONTROL

As far as the climate is concerned, the Japanese beetle has apparently found in western New Jersey and eastern Pennsylvania exceedingly favorable conditions for its multiplication and establishment. Since the beetle's first appearance in 1916 no climatological condition has offered any check to the rapid numerical increase of the species. Occasionally it has been found that when the eggs are laid in very sandy soil and the weather is particularly dry many of the young larvae are destroyed owing to the dry condition near the surface of the ground. No condition of heat has been noted which has been injurious to the larvae or eggs, provided the soil is moist.

When the ground is very dry the larvae show a tendency to form cells and become somewhat less active than when the soil is moist. During extended periods of rainy weather areas have been flooded for periods of two or three weeks, apparently without any injurious effects upon the larvae in the soil.

During the past three winters the second and third instar larvae successfully passed the winter within 2 inches

of the surface of the ground, in plowed land. A minimum temperature of 8° F. was recorded 4 inches below the surface. This would indicate that the larvae can successfully withstand low temperatures.

Observations made in 1921 indicated that the larvae of the Japanese beetle were subject to certain diseases, presumably of bacterial, fungous or protozoan origin. In 1922 an intensive study of micro-organisms affecting the larvae of the Japanese beetle was begun. It was found that several species of bacteria are highly pathogenic to these larvae. Some of these organisms have not hitherto been described. One species has been found which kills the larva and causes a partial disintegration of the body within 24 hours after innoculation. Apparently the most probable means of entrance by bacterial infection is through some injury to the larva. There is evidence, however, which points to the probability that infection also takes place through the walls of the alimentary canal of the larva.

Several species of fungi have been found which attack the larvae under favorable conditions of temperature and moisture. Three species of fungi, including the green muscadine fungus Metarrhizium anisopliae Metsch., have at times been found in abundance and attacking the larvae. During the winter of 1922, cultures of Isaria densa were received from the laboratory of Doctor LeMoult, at Nevers, France. In the fall of 1923, plots of ground were inoculated with this fungus and during the spring of 1924 larvae were recovered from these plots affected with the fungus. Whether fungi will become an important factor in the control of these insects

is problematical, because the effectiveness of fungi and bacteria is dependent upon favorable conditions of moisture and temperature. It is planned in the near future to inoculate larger plots in the infested area with the various bacteria and fungi which have been found attacking the Japanese beetle larvae.

The rapid increase of the Japanese beetle population in this country during the period of 1916 to 1920 pointed emphatically to the absence of its parasitic enemies. This insect in its Asiatic establishments is kept within reasonable population limits largely through the activity of parasites. Consequently in 1920 experts of the Federal Bureau of Entomology were sent to Japan to investigate the most important native parasites and to consider the possibility of their introduction into this country. Some of the early shipments of parasites were lost because the insects failed to survive the conditions peculiar to these shipments. However, constructive modification of the method of packing resulted in the introduction into this country of parasite shipments of satisfactory survival. Fourteen different species of parasitic insects have been liberated since 1924. Only five of these species have shown ability to establish themselves, and two of these show promising parasitism. Furthermore, these two parasites are specific for the Japanese beetle, consequently their establishment in a lightly infested area is of a very doubtful result.

Of the parasites attacking the adult, a tachinid fly, Centeter cinerea, is the only one worthy of mention. It was first introduced in 1922, and by 1923 had definitely colonized itself near Moorestown. By 1930, seven established

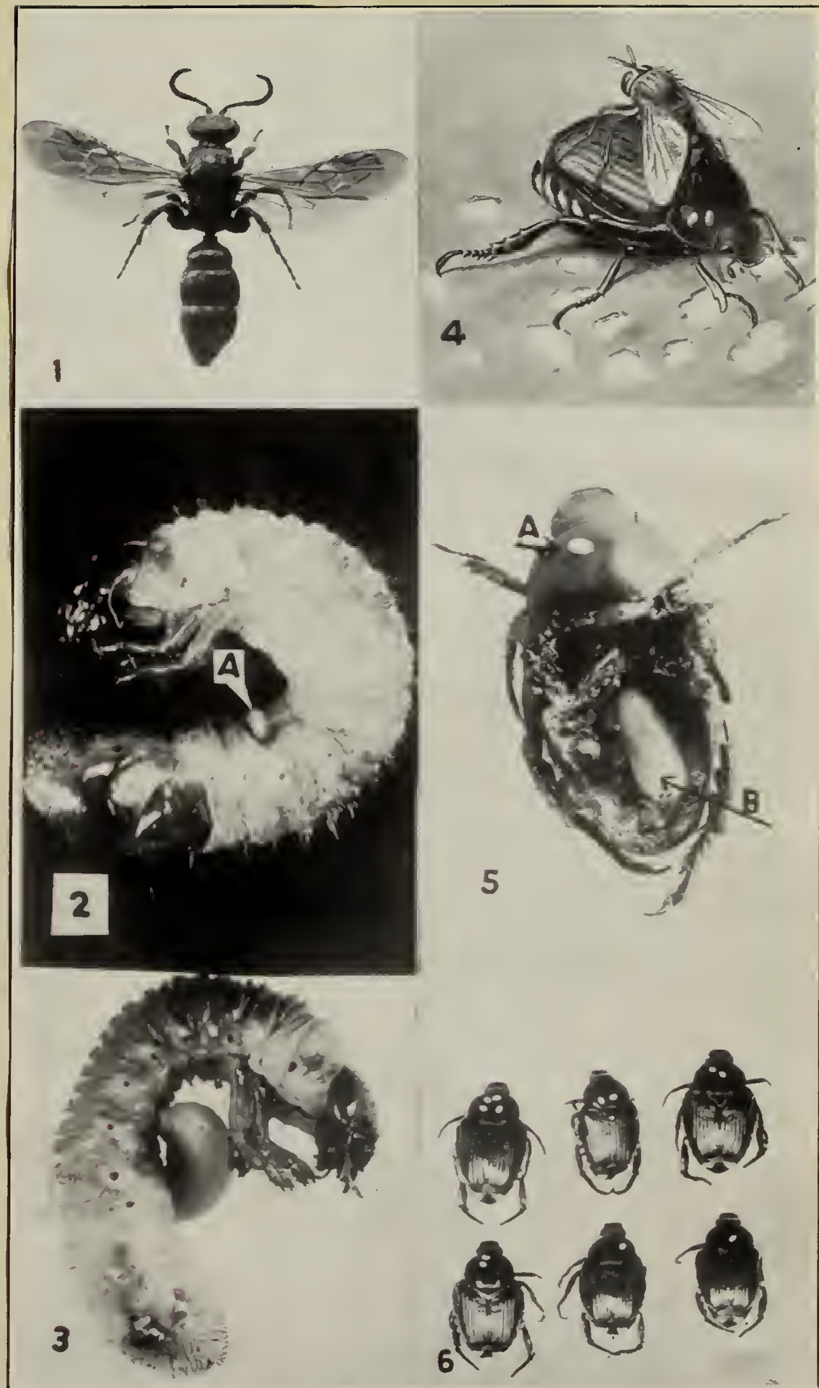


FIGURE 9.—Parasites of the Japanese Beetle. See opposite page
(Courtesy Japanese Beetle Research Laboratory.)

1. Fall *Tiphia* parasite. Female. Enlarged three times.
2. Japanese beetle grub with egg (A) of *Tiphia* parasite attached. Enlarged five times.
3. Japanese beetle grub with larva of *Tiphia* parasite attached and feeding. Parasite larva about one-third grown. Enlarged five times.
4. *Centeter* parasite fly laying eggs on Japanese beetle. Enlarged two times.
5. Japanese beetle cut open to show *Centeter* parasite larva (B) feeding. *Centeter* egg shown at (A). Enlarged three times.
6. Japanese beetles with *Centeter* parasite eggs attached. Enlarged about one-half.

colonies are known to exist.

The *Centeter* parasite passes through the winter as a puparium in the ground. The adult fly appears about the middle of June and persists until the middle of July. The ratio of males to females is two to one. The only known function of the male is fertilization of the female. The adults feed on aphid honey dew and on the exudate from nectar glands found on certain leaf petioles. The female attaches the eggs to the thoracic cover of the Japanese beetle. Usually only one egg is laid on a beetle; however, three and less frequently four have been observed. About a second is required for the attachment of the egg during which time the beetle shows resistance. The average number of eggs laid per female is forty. The eggs are oval discs about one thirty-second of an inch in diameter. The incubation period is 24 hours, after which time the larvae hatch and begin feeding on the vital organs of the beetle. The beetle is killed within five days. The beetle usually takes refuge by burying itself in the ground during the last stage of its parasitism. The parasite larvae are matured in about ten days, they transform into a puparium for the winter period. The *Centeter* will lay its eggs on the Japanese beetle only. The *Centeter* fly is not too well synchronized with regard to its emergence, to the emergence of the Japanese beetle. In view of this discrepancy many cocoons are held in a controlled temperature chamber at the laboratory at Moorestown for the purpose of regulating the emergence of the fly so as to coincide with the emergence of the adult of the Japanese beetle.

Of all the Japanese beetle parasites, the wasp, *Tiphia*

popilliavora, parasitic on the larvae, is at present the most promising. At least fifty established colonies of this insect are now known to exist in New Jersey.

The Tiphia passes the winter in the ground as a cocoon. The adults appear in early August and persist until late September. The ratio of males to females is about one to one. The only known function of the male is the fertilization of the female. The females, probably aided and guided by a distinctive odor, find their way into the ground to attack the Japanese beetle grubs, usually in the second or third instar stage. The grub is stung and paralyzed, whereupon an egg is attached to the suture between the fifth and sixth abdominal segment. Only one egg is deposited on the larval body. Apparently the eggs are laid at such intervals that the female reappears above ground between the egg laying operations. Forty eggs is the average for the females. The eggs are elliptical and about one-fourth the size of Japanese beetle eggs. The female Tiphia will deposit eggs only on the Japanese beetle grubs. If these grubs are not found, egg laying will be discontinued. The adults feed on the inflorescence of wild carrot (Daucus carota)almost exclusively. The incubation period of these eggs is from 7 to 8 days. The larvae which hatch from these eggs consume the Japanese beetle grubs. The duration of the Tiphia larval period is from 20 to 30 days, after which time a cocoon is spun around the larvae in preparation for the quiescent period.

During the seasons of 1920 and 1921, Mr. Clausen made shipments of a predacious carabid beetle (Craspedonotus tibialis Schaum) which gave promise of being an active enemy of all stages of the Japanese beetle. Eggs were obtained and larvae in the first, second, and third instars developed later;

apparently, however, they could not survive the winter conditions in New Jersey, as no trace of the live beetles in any stage could be found when the soil was examined in the spring of 1922.

In May, 1921, Messrs. Burgess and Collins, of the gipsy moth laboratory at Melrose Highlands, Mass., sent shipment of live adult Carabus nemoralis Mull. to be tested as enemies of the Japanese beetle. These carabids arrived in good condition, and were placed in cages and fed larvae of Popillia japonica and earthworms. It was found, however, that the adult carabids fed largely at night and only on the surface of the ground. During the day they remained hidden under boards, stones, or other rubbish. Although the beetles readily ate the Japanese beetle larvae when they occurred on the surface of the ground, no evidence was obtained to show that they would dig down into the soil to find them. Several cages were prepared with soil in which were placed numerous larvae of the Japanese beetle. Adults of C. nemoralis were released in the cages, but the beetles starved to death, even though there was an abundant supply of larvae less than 1 inch below the surface of the soil. Further experiments indicated that C. nemoralis is decidedly limited in the amount of feeding which it would do on Popillia japonica, and that from its habit of feeding above ground it would be of less value than several species of carabids which are indigenous to New Jersey and Pennsylvania.

Collections of live adult Harpalus vagans Lec. and Chlaenius sericeus Forst, were made at Trenton, N. J., by Harry B. Weiss and sent to Riverton. Both species fed on the larvae of Popillia japonica.

The larvae of Calosoma calidum Fabr., Poecilus lucublandus Say, Harpalus caliginosus Fabr. , and Staphylinus mysticus Er.

have been found to feed on the larvae of the Japanese beetle.

The larvae of Tabanus sulcifrons Macq., feed readily on the immature forms of Popillia. To some extent T. atratus Forst. in its larval stages may also feed on them. At present, however, there is no evidence of any decided increase in the numbers of the various native species which are predacious on Popillia japonica.

Among the natural enemies of the Japanese beetle which are native to the United States, the birds are apparently the most important. The purple grackle or crow blackbird (Quiscalus quiscula) and starling (Sturnus vulgaris) are common wherever the beetle is abundant, and the entomologists have found beetle remains in the stomach of the purple grackle, king bird (Tyrannus tyrannus), and cardinal (Cardinalis cardinalis); and E. A. Chapin, then of the Bureau of Biological Survey, who made a brief study of the birds in the beetle area in September, 1919, has found beetle remains in the stomachs of the starling (Sturnus vulgaris), meadowlark (Sturnella magna), and catbird (Dumetella carolinensis), as well as of those mentioned above. During the beetle season in 1920, July 8 to August 20, C. W. Leister, also of the Bureau of Biological Survey, studied the birds of the Japanese beetle-infested area in relation to the beetle, and examined the stomachs of 141 birds. He found Japanese beetles in 74 of the stomachs, or 52.5 per cent of those examined.

There is every evidence that the same birds that feed on our common white grubs likewise feed on grubs of the Japanese beetle, and the most important of these are the crow, purple grackle, starling, and bobwhite.

Pheasants are known for their fondness for beetles of

all kinds. A pair of English pheasants (Phasianus colchicus) furnished by the New Jersey State Fish and Game Commission showed a great liking for both live and dried Japanese beetles. An attempt has been made to colonize these birds in the infested area, and to this end the New Jersey Legislature has passed a law prohibiting the killing of pheasants in certain designated areas for a period of five years, and the Burlington County Game Protective League has distributed pairs in a number of places in the beetle-infested regions.

Toads eat a great many of the beetles and, according to Mr. Leister, the beetles made up an average of 22 per cent of the stomach contents in the seven toads examined.

No records have been made of mammals feeding on either grubs or beetles, but there is evidence that such animals as the skunk and mole feed on the grubs.

ARTIFICIAL CONTROL

The object of the quarantine because of the Japanese beetle is to retard the artificial spread of the insect by regulating the involved important channels of commerce. The existence and enforcement of this quarantine makes nursery stock grown within the infested area acceptable to states outside the infested area. In the absence of such a quarantine, plant commerce within the area would become very much demoralized because of refusal of the plant quarantine authorities of the non-infested states to accept such uncertified nursery shipments. Furthermore such a retardation of the artificial spread is advantageous in so far that large-scale control measures may be more economically and effectively applied than would be the case if the spread of the insect were permitted

to continue unrestricted through all the channels of plant distribution.

The first Federal Japanese Beetle Quarantine (Quarantine 35) was made effective June 1, 1919. This quarantine regulated only the movement of sweet corn from three Burlington county townships. The Japanese beetle quarantine is a restrictive order issued by the Secretary of the United States Department of Agriculture prohibiting the movement from the Japanese beetle regulated area, except under certain conditions, of nursery, ornamental and greenhouse stock, all plants, plant roots or parts of plants, sand, soil, earth, peat, compost and manure, cut flowers and farm products. The Japanese beetle regulated area at this time involves the entire State of New Jersey. The quarantine covering nursery, ornamental and greenhouse stock, all plants, plant roots, parts of plants, sand, soil, earth, pear compost and manure is effective throughout the entire year. The quarantine on cut flowers and farm products is in effect only during the period of June 15 to October 15, during which period the adult beetle may be in flight.

Simultaneously with the promulgation of the Federal Japanese beetle quarantine, the Secretary of the New Jersey State Department of Agriculture promulgates a state Japanese beetle quarantine which parallels, almost entirely the Federal quarantine. A State quarantine is necessary because the Federal quarantine has no jurisdiction over the movement of susceptible materials within the State of New Jersey. Fundamentally, the Federal quarantine applies only to the interstate shipments.

During the early extermination work use was made of

sodium cyanide in solution. This material was satisfactory from the standpoint of its toxic effect on the grub, but it was distinctly injurious to the sod, and the cost of labor, material, and special equipment for applying the solution was so great as to preclude its use on a large scale. Among the many other materials which have been tested are paradichoro-benzene, orthodichlorobenzene, and calcium carbide. Of these, only paradichlorobenzene gave satisfactory results. When it was drilled into the soil at the rate of 300 pounds to the acre, as high as 75 per cent mortality of the larvae could usually be obtained. At present prices, however, the cost of materials amounts to about $60 per acre; and, since it is effective only in fields where conditions are suitable, its usefulness for this purpose is limited.

A practical method of destroying larvae in large numbers on golf greens has been devised (6), consisting of treating the soil with a dilute solution of carbon-disulfide emulsion. The emulsion is prepared by mixing 1 part by volume of cold-water-soluble resin-fishoil soap, 3 parts of water, and 10 parts of carbon disulfide. The soap and water should be agitated in a churn (an ice-cream freezer is also very satisfactory for this purpose) until an even mixture is obtained; to this the carbon disulfide is added and the whole churned until it emulsifies, as indicated by a change in color and a creamlike of the liquid. One quart of the emulsion thus obtained is stirred into 50 gallons of water, and the resulting mixture is applied at the rate of 3 pints to each square foot of turf. In order properly to treat a golf green the turf should be maintained in a moist condition for at least

10 days prior to the application of the insecticide. The green should then be laid off into areas of about 1,200 square feet and the proper quantity of solution applied to each area. Formerly the mixture was run on to the green from a spray tank. This method of procedure has been improved upon, and in the fall of 1924 a special attachment was put on the market, to be connected to the water main for regulating the quantity of insecticide entering the water stream, thus eliminating the use of a tank. In applying the material care should be taken that the turf is not flooded. The liquid should be applied lightly and allowed to soak in and the operation repeated until the required quantity of solution has been used.

The quarantine regulations which have been and are now being enforced for all classes of nursery stock which are commonly shipped with soil about the roots require before such shipment is permitted the treatment of the soil in such a manner as to insure the death of any stage of the Japanese beetle which it may contain.

Certain arsenates, such as those of lead, iron, zinc, and copper, have been mixed in varying quantities with the soil in which potted plants are grown, with the object of obtaining larval mortality with no accompanying plant injury; of these, acid lead arsenate has given the most satisfactory results. In the case of acid arsenate of lead, results to date have shown that many plants grown in soil treated with this material are entirely resistant to any ill effects and others are slightly injured, but some species are very susceptible and suffer considerable injury from the effect of the arsenical in the soil.

Attempts were made to kill the larvae in soil by means of several so-called contact insecticides, among which may be mentioned bichloride of mercury, various cresols, phenols, petroleum, mineral oils, and other materials, but in all cases they have proved to be injurious to plant growth when used at dosages toxic to the larvae.

More than 40 organic chemicals have been used in treating infested soil balls, among them being ether, petroleum-ether, toluene, acetic-ether, nitrobenzene, chloroform, and others. In most cases these have been found more or less toxic to the to the larvae, but the resultant injuries to the plants have been such as to preclude their use for this purpose.

Several greenhouse concerns within the infested territory are now using a method, worked out by the experiment station in Trenton, N. J., for fumigating their potting soil. It is summarized as follows:

> Carbon disulfide must be placed in the soil to kill the larvae.
>
> It seems advisable to use not less than 13 fluid ounces (1 pound) to a cubic yard of soil with an exposure of 48 hours at a temperature above 50° F.
>
> Dosage holes must be arranged so that the diffusions regions from the various injection holes overlap and thus assure all parts of the soil being treated. It is suggested that when 18 inches of soil has been placed in the fumigation box, injection holes should be made 6 inches deep in rows 12 to 15 inches apart and 12 to 15 inches distant in the rows, with $1\frac{1}{2}$ ounces of CS_2 in each injection hole. After closing the hole, 18 inches more soil is placed in the box and the process is repeated until the box is

filled.

Experiments have been carried out to test the effect of vacuum, pressure, and their alternation, upon the larva and the plant. The apparatus used was specially designed for these studies and has a working range from 28 inches of vacuum to 150 pounds pressure. The results from a practical standpoint have been negative in that the effects upon the plant and the larva have been similar, being a rupturing of the tissues of both the plant and the insect when any sudden change from atmospheric pressure is made. Gradual changes from the normal proved to be neither harmful to the larva nor injurious to the plant. When various gases were used as fumigants under vacuum or pressure, the results were practically the same as when the same materials were used under normal conditions.

Experiments with hot water to kill the larvae in the soil have been carried out by Leach, and show that water at a minimum temperature of 100° F. will kill the larvae immersed in it for 45 minutes, but when the roots of living plants are subjected to the same treatment even the more resistant varieties are likely to be seriously injured.

Detailed studies have been made by Leach and Johnson on the use of various chemical dips for destroying the larvae in soil about the roots of plants such as Japanese iris, Phlox, and sedum. The results of the work, published as Department Bulletin 1332, indicate that oil of wormseed and carbon disulfide are the best materials for use in this connection. These compounds when emulsified with soap are both capable of forming stable emulsions, the toxic principles of which are retained indefinitely. The active ingredient of oil of wormseed is ascaridole, $C_{10}H_{16}O_2$. Certain other consti-

tuents of the oil are also toxic in varying degree. The concentration of the dip as recommended is stated in terms of the ascaridole content of the oil. When the Japanese beetle larvae are immersed for six hours in the wormseed oil dip, the concentration of which is equal to 0.5 cubic centimeter of ascaridole to 3 liters of water, the larvae are killed, provided the temperature of the dip is maintained between 65 and 70° F. Temperature is a limiting factor in this treatment, and under no circumstances must it be allowed to fall below 65° F. The general recommendations are that Japanese iris and sedum be immersed for 15 hours, and perennial phlox from 9 to 18 hours, depending upon the quantity of soil present in the roots. These periods of time provide an ample margin of safety over the time actually required to obtain the death of the larvae.

It has been found advisable, from the standpoint of cost, to employ carbon-disulfide emulsion for the treatment of peony roots. The plants are immersed for a period of 15 hours in a dip the concentration of which is equivalent to 0.5 cubic centimeters of carbon-disfulfide emulsion in 1 liter of water.

Carbon-disulfide emulsion is also being used extensively for the treatment of many other kinds of plants with soil about the roots, including arborvitae, spruces, hemlocks, rhododendrons, azaleas, blueberries, hydrangeas, ferns and similar plants, besides numerous varieties of potted stock.

Commercial lead aresenate is the most commonly employed arsenical for insect control. It is an extremely finely divided white powder, practically insoluble in water, and when sprayed alone it is very unadhesive to foliage.

Coated lead arsenate, perfected at the Japanese Beetle Laboratory at Moorestown, independent of an already operative patent-right, consists of an intimate mixture of a soap (lead oleate) and the commercial lead arsenate. Coated lead arsenate adheres to sprayed leaves very tenaciously, as a matter of fact usually persisting throughout the beetle feeding period.

Green lead arsenate, essentially the commercial lead arsenate dyed green, was developed at the Japanese Beetle Laboratory in compliance with many requests for an arsenical which will not discolor the foliage. However, plants sprayed with green lead arsenate are more severely damaged than plants sprayed with coated lead arsenate, principally because the white color of the coated lead arsenate which visually repels the beetle is lacking. Green lead arsenate is the more effective killing agent.

Silicated pyrethrum soap is a contact insecticide which when sprayed on the beetle results in its death. However, killing beetles on a plant does not prevent a reinfestation. The use of this insecticide in Japanese beetle control is very limited.

Lime and wheat flour used in combination with lead arsenate are effective as stickers in increasing the adhesiveness of the lead arsenate. When used alone they serve as repellents because of the white discoloration of the sprayed foliage.

One of the early observations (1918) of the Japanese beetle research work was the preference shown by the beetle for smart weed. Later observations indicated that the Japanese beetle was also strongly attracted to sassafras (1921) and to geranium (1923). Speculation as to the reason for these

Figure 10.—Component parts of the mechanical trap and their assembled use. (Courtesy Japanese Beetle Research Laboratory.)

specific attractions led to the belief that the insect is highly sensitive and strongly responsive to certain volatile constituents. A fractional separation of these volatile oils demonstrated that the beetle is strongly attracted to an oil known as GERANIOL and to a lesser degree to another, known as EUGENOL. This discovery has been the basic premise of mechanical trap construction. The geraniol and eugenol as used in the bait for Japanese beetle traps are plant extracts. Geraniol is the principal component of lemon-grass oil and palmarosa oil, from which it may be extracted by fractional distillation. Eugenol is a distillation product of clove oil.

The mechanical trap, after having undergone slight modification, is today a device as illustrated in Figure 10. The body of the trap is seven inches high and seven inches in diameter. It consists essentially of four parts: a funnel with a surmounted baffle, a bait receptacle, and the body, all of tin construction, and a glass jar. The funnel (one of the ordinary type) causes the descent of the involved beetles to the glass jar receptacle below. The baffle, usually about five inches high, is very effective in increasing the number of beetles trapped because of the fact that beetles flying within its range have their flight suddenly terminated and are dropped into the funnel. The bait receptacle, which rests on the floor of the body of the trap, has a central opening through which the neck of the funnel projects. It has a perforated bottom, which permits passage of air through the bait for the volatilization of the geraniol and eugenol. The floor of the body of the trap is likewise supplied with numerous small holes for the passage of air through the bait receptacle.

The following bait formula is recommended for use with beetle traps:

Geraniol (at least 58% pure)......	4 teaspoonfuls(15 grams)
Eugenol (U. S. P.)................	$\frac{1}{2}$ teaspoonful(1.5 grams)
Bran..............................	$1\frac{1}{2}$ cups (75 grams)
Water.............................	1 tablespoonful(13 cc.)
Molasses..........................	$2\frac{1}{2}$ tablespoonfuls(39 cc.)
Glycerine, C. P...................	$1\frac{1}{2}$ teaspoonfuls(6 cc.)

The total weight of the above mixture is approximately 150 grams or one-third of a pound. Bait prepared according to the above formula is usually available at retail insecticide stores within the heavily infested area.

In the experimental use of traps over a period of five years several fundamental conclusions have been made possible.

1. The use of a trap or traps in a given area will increase the number of beetles in the area by virtue of the attractants in the bait.

2. Traps do not trap all the beetles attracted. Their efficiency, which is quite variable, is dependent on many factors.

3. The use of traps does not protect vegetation immediately surrounding them.

4. When traps are employed, it appears that females within their range are subject to two strong impulses: first, the response to the attraction of the geraniol and, second, the response to the physiological urge to deposit eggs. That response to the egg laying impulse frequently takes priority to the response of attraction to the trap is true and has been substantiated by the finding of many more larvae in lawns on which traps were placed.

5. Therefore, traps preferably should be placed on lawns which have been treated with lead arsenate for larval control.

6. Traps are more effective when placed in the sunlight and painted green in color.

7. The trapped beetles should be removed daily. Otherwise the odor of the decomposiong beetles will obscure the odor of the geraniol.

8. Beetles can be killed by submerging them in boiling water.

The use of electricity for the control of insects is of rather recent origin. The principle involved is that of electrocution. The trap, as commonly used, consists primarily of a step-up transformer and horizontally wound uninsulated copper wire. The trap consists essentially of four upright posts about 20 inches high and about 20 inches apart, arranged in the form of a square. The copper wires are so spaced that the inter-wire space is slightly greater than the depth of the beetle body. The arcing potential of this wire separation is determined and then roughly reduced one-half for insect electrocution.

The source of current is the usually available 110 volt, 60 cycle alternating current. This potential is stepped up to about 12,000 volts, which will not arc across the three-eighths inch gap between the wires. However, should a beetle body become interposed between two of these wires, the insulating (dielectric) value of the surrounding air is immediately lost and a spark jumps from the wires to the insect body. The charge passing through the insect body usually causes loss of appendages and general disruption of the body proper. An open dish of geraniol placed in the middle of the trap is the attractant used.

Electrical traps of the type here described embody a

principle showing considerable promise. However, their present state of perfection does not display the practicability desired. The cost of operation of one of these traps is approximately that of a one hundred watt lamp.

CLIMATIC CONDITIONS IN THE MAIN FIELDS OF INVESTIGATION IN JAPAN

A comparison of the climatic conditions in the various regions in which work was conducted with those in the infested area in American is of value from two points of view: (1) In relation to the reactions of Popillia japonica itself under varying conditons, and (2) as bearing upon the question of establishment of the oriental parasites in this country.

Figure 32 gives a graphic representation of the mean monthly temperatures throughout the year for Yokohama, Koiwai, and Sapporo, Japan, and Suigen, Chosen, the four main centers of investigation. These graphs show a considerable uniformity in certain respects, the peak in each case occurring in August and followed by a sharp decline. Sapporo is uniformly 6 to 10° C. (11 to 18° F.) cooler than Yokohama; with Koiwai occupying an intermediate position. In Chosen, on the contrary, the summer temperatures approximate those at Yokohama, whereas during the winter they coincide closely with those of Koiwai and Sapporo.

A comparison of these records with the graph shown in Figure 33, which is for Philadelphia, brings out several interesting points. The winter temperatures at the latter place are 4 to 6° C. (7 to 11° F.) above those of Koiwai, Sapporo, and Suigen, whereas the graph for the spring months follows very closely that of the latter place. The maximum summer temperature is attained in July rather than August, and the

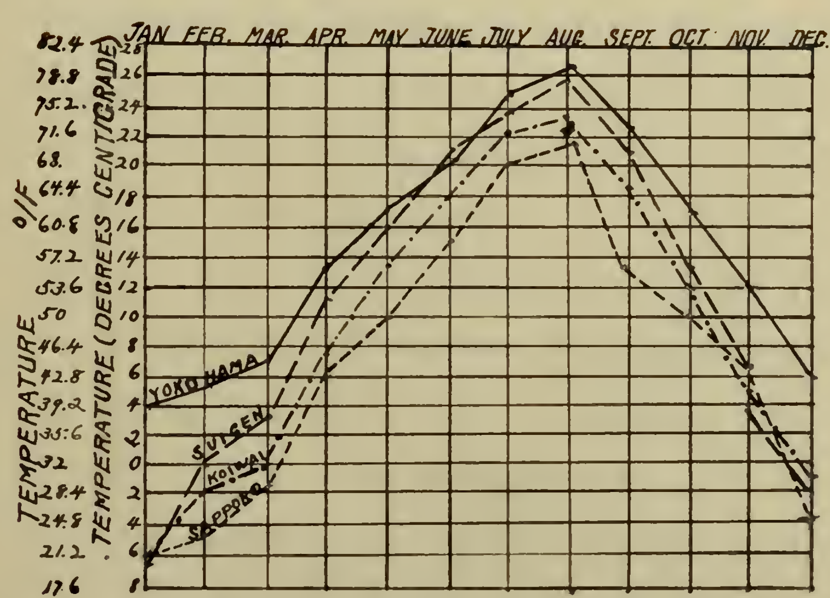


Fig. 32.--Curves showing the range of the mean monthly temperature for Yokohama, Koiwai, and Sopporo, Japan, and Suigen, Chosen. Temperature based on a three-year average, except Yokohama, which is for two years.

decline which follows is more gradual. Thus it is seen that the growing season at Philadelphia is nearly six weeks longer than at Koiwai or at Sapporo, and this in a measure explains the more or less biennial cycle of *Popillia japonica* in northern Japan as contrasted with normal one-year cycle at Yokohama and in America.

Figure 34 shows the mean monthly precipitation for Yokohama, Sapporo, and Suigen, based on a two-year average, and Figure 33 shows that for Philadelphia on a 50-year average. Unfortunately it was not possible to obtain records for Koiwai, and although those for Morioka, 10 miles away, were available yet these were in no wise comparable to the Koiwai figures. A heavy snowfall occurs in the winter months and fairly heavy rains are not infrequent throughout the remaining portions of the year, in fact daily showers are a rather notable feature.

It is seen by reference to Figure 34 that rainfall at Yokohama was very light in the winter but fairly heavy in the summer months, whereas at Sapporo the heaviest precipitation was recorded in the winter, with the lowest points reached in the early summer months. At Suigen, Chosen, however, the winter and spring precipitation is very low, followed by a period of exceedingly heavy rainfall during July and August. The rainfall during the 24 hours of July 28, 1922 totaled 11.3 inches. A comparison of these graphs with that of Philadelphia shows that Sapporo, and probably Koiwai as well, correspond fairly closely, whereas the heavy summer and light winter precipitation at Yokohama and Suigen are far removed from it.

A consideration of the two factors of temperature and rainfall in the various localities reveals the fact that conditions at Koiwai and Sapporo more nearly approximate those

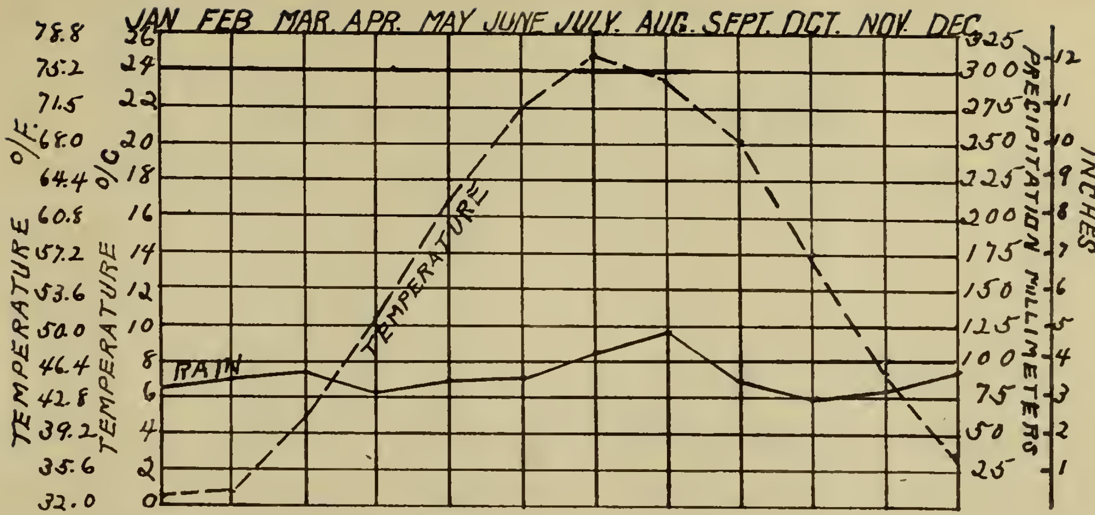


Fig. 33.--Curves showing the mean monthly temperature and precipitation for Philadelphia, based on a 50-year average.

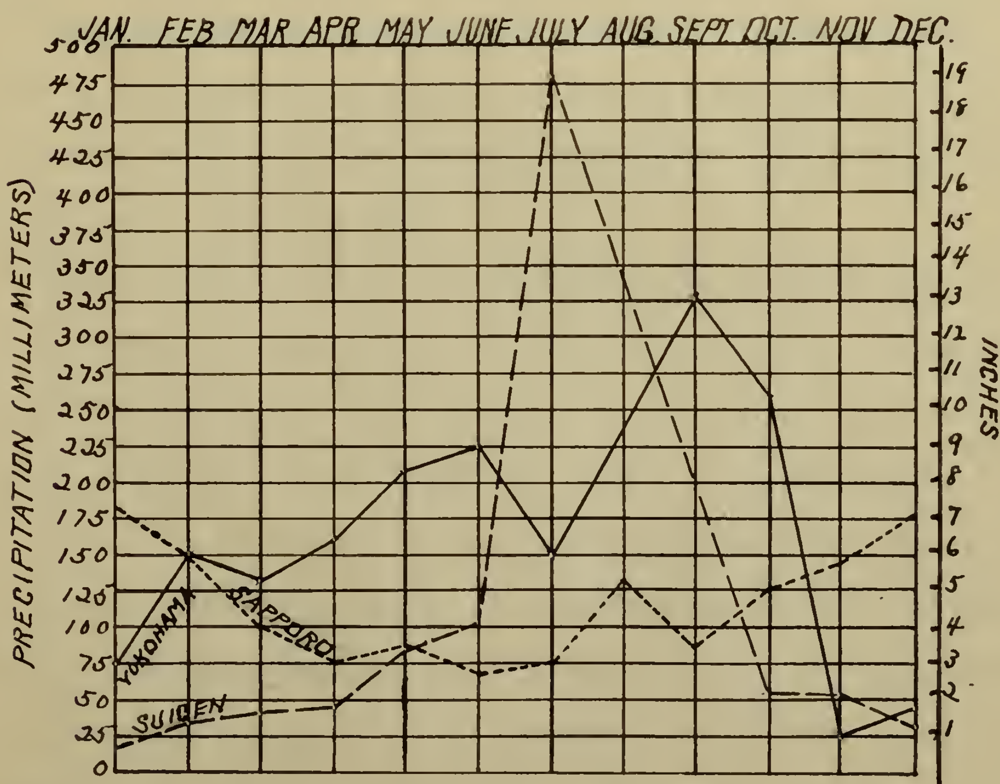


Fig. 34.--Curves showing the mean monthly precipitation for Sapporo and Yokohama, Japan, and Suigen, Chosen, based on a two-year average.

of the infested area than do those at Yokohama and at Suigen.

AGRICULTURE AND NATURAL LANDS OF JAPAN AND CHOSEN IN RELATION TO POPILLIA

Since agricultural and natural conditions have an important bearing upon the fauna, it is relevant here to make a few remarks concerning them.

The combined area of the main islands--Honshu, Kyushu, Shikoku, and Hokkaido--is 140,000 square miles, or approximately the same as the area of Montana. A large part of this area consists of mountainous country heavily forested with virgin and planted forests. Much of the land is worthless "hara," or rolling prairielike lands at the foot of the higher mountain ranges. These are densely covered with low, persistent bamboo grasses. Sand hills and plains along the coast also form a distinct habitat of considerable extent. About 17 per cent of the total land area is estimated as arable, although only 12 per cent is under actual cultivation.

The limited area of arable land and the food supply demands of this densely populated country have made Japanese agriculture one of the most intensive in the world. Rice is the chief food and it is grown largely in flooded plots called "paddy fields," one-half of the agricultural lands being given over to this crop. The average landholding in this agricultural area is 2½ acres per individual. Where physiographical conditions were originally unfavorable, they have been altered if possible to suit rice growing. This has resulted in the terracing of hill and mountain sides and the cutting up of the lowlands into innumerable paddy fields to accommodate them to the varying water levels. Where it is possible to drain the paddy fields they are immediately prepared for wheat or

barley as a successive crop. Areas not suited to rice culture are devoted to dry farming, including the growth of wheat, barley, rye, millet, soybeans, and such vegetables as daikon radishes, eggplants, sweet potatoes, taro (Caladium colocasia), and Japanese onions (negi). All these food plants, including such grains as wheat and rye, are cultivated and fertilized intensively during their growing period, and often eggplants, onions, or cucumbers are grown between the rows of grain.

On the island of Hokkaido, natural and agricultural conditions more nearly approach those of our Eastern States. There are large areas of natural forest similar in makeup to our own forests, the trees consisting of species of oak, maple, beech magnolia, chestnut, birch, and pine. The extent of waste lands in Hokkaido compares with that of Pennsylvania. Agricultural landholdings in this region are somewhat larger than in Honshu and the method of cropping is similar to that in America. Corn, wheat, oats, barley, rye, millet, and some rice are the chief grains grown. Grasslands suitable for grazing are more abundant here than elsewhere in Japan, and dairying and stock farming are resulting industries.

Koiwai, near Morioka on the island of Honshu, is not in the zone of intense agriculture, but is in reality one large estate of 7,500 acres in an old volcanic upland of sufficient for the development of natural grasslands and grains, such as corn, wheat, and oats, and the methods of cropping are like those employed in the eastern section of the United States. The forest areas here are entirely artificial, consisting for the most part of regular plantings of chestnut, larch, and pine.

These agricultural conditions may be a factor influencing the relative abundance of Popillia japonica within certain regions. From Sendai southward is the region of intense cultivation, as described in the preceding paragraphs, and within this region Popillia is much less abundant than northward. This lack of abundance may be the result of the intense cropping of the soil and the flooding of the paddy fields, practices which are most unfavorable for soil-inhabiting insects. Further, within this region there are very few grasslands other than dense growths of low bamboo grass, these latter being rarely inhabited by Popillia. On the other hand, north of Sendai, including Koiwai and the island of Hokkaido, Popillia is more abundant than elsewhere in Japan. Here agriculture is not so intensive, waste lands are more extensive, and sod or pasture lands in which Popillia breeds are not uncommon. Food plants suitable for the adults, however, are no more abundant here than in the south.

The fore-going points have been considered for the reason that they are thought by some to be the chief factors influencing the distribution of Popillia; but some entomologists assert that this insect is more abundant in the north because it is by nature a species which has become adapted to a northern habitat. At Tokyo and Yokohama, where sod lands have been artificially produced in lawns and golf links, Popillia does not increase and take advantage of these breeding grounds.

In Chosen agricultural conditions, although similar to those of Japan, are not so intensive. The outstanding feature in that country is the lack of forests. As a result of this

forest destruction vast mountain areas have lost their soil and support no vegetation. In the lowlands grasses grow in all the waste places and in these areas the Chosen species of Popillia are commonly found.

CONCLUSION AND SUMMARY

The importance of the Japanese beetle in the area where it now occurs and the damage which it may cause when introduced into regions which are not as yet infested are mooted questions. Those who have not seen the damage done by the insect should not be misled into believing that it causes a wholesale defoliation of the trees and a devastation of the crops. The gregarious habits of the insect result in heavy infestations in certain localities where it has occurred for a number of years. Its preferred food plants, unless properly protected by sprays, are to a large extent defoliated. Neighboring localities, however, may have very few beetles and little damage would be apparent to a casual observer. In the region most heavily infested at the present time the injuries are found to occur on a wide variety of plants. In central New Jersey large acreages of early and late ripening varieties of fruits, sweet and field corn, cereal, forage, and vegetable crops are grown, in addition to innumerable shade and ornamental trees and shrubs. The losses sustained by the New Jersey growers through the damage done by the beetles to any one particular crop are probably less than would be the losses if the beetles occurred in a locality where fewer crops are grown and a smaller number of them affected. The Japanese beetle feeds on cotton, on the blossoms and foliage of red clover, on string beans, and on various other plants. It is believed that if the insect should be introduced into an area where environmental conditions were favorable and these or similar plants were grown extensively, the damage done to such crops would be much greater than the damage already wrought under

the conditions obtaining in New Jersey.

It has been found that any plants which can be sprayed with an arsenical poison may be successfully protected against the attacks of the Japanese beetle. From the standpoint of the production of fruit or protection of shade trees, this insect does not offer a menace which can not be prevented or controlled. When the beetle occurs abundantly in fruit-growing sections or residential districts, however, the growers will be subjected to an additional expense to protect their plants from a more or less serious loss. If this insect should become distributed widely the total expenditure of money by the people to protect their plants and crops would in the aggregate represent an enormous amount. As it happens, an additional spray is required on most fruits to prevent the attacks of the Japanese beetle. It can therefore be considered that, even with effective methods devised for the protection of crops, an additional expense is placed on the people in communities infested with this insect.

It appears that the insect will normally spread outward at the rate of between 10 and 15 miles each year, unless it is carried to a greater distance through some artificial agency. The operation of the quarantine on farm produce and on the movement of nursery stock with soil about the roots has thus far apparently been successful in preventing the extensive spread of the insect. The experience of those operating the quarantine indicates that the time will come when a change may be advisable in the method of enforcement. As the insect continues to spread it will probably reach particular areas which will at least temporarily, if not permanently, stop its movement in certain directions. Such barriers may be either

ecological or topographical in character. Quarantine lines could be arranged to follow the areas where the beetle is checked naturally in its spread. Under these conditions embargo action on farm produce moving from the infested area might be advisable, as well as a continuance of the strict regulation of the movement of nursery stock and infested soil. A quarantine thus established would in all probability be effective for many years in preventing the long-distance spread of the beetle. It is obvious that, while a quarantine over a relatively large area means the expenditure of large sums of money it will be more than justified if the spread of the insect can be prevented or held back for several years. If the quarantine were to be dropped and the beetles were to spread over a large territory, the losses which would result, both through the destruction of crops and in the expenditure of funds for their protection, would in the aggregate constitute a sum greatly in excess of the amount necessary for quarantine purposes.

The outlook at the present time is most hopeful. The development of spray materials which are giving excellent protection to plants as well as a definite killing of the insects, and the finding of effective methods of their application, afford the fruit growers and others a means of preventing serious losses. The method of soil treatment worked out for the control of the grubs offers relief to those who have been suffering damage to their sod lands. The establishment of at least one species of parasite of the Japanese beetle in this country will undoubtedly result in a gradual diminution in numbers of the beetle. There is every reason to believe that

the Japanese beetle will gradually be brought under control and its injuries almost if not entirely prevented.

The Japanese beetle, an insect native on the islands of Japan, was introduced into the United States in the vicinity of Riverton, N. J., some time prior to 1916. Since that time it has increased in numbers and spread until at the end of the summer of 1923 it had infested an area of approximately 2,500 square miles in New Jersey and Pennsylvania.

From the rate at which the insect has increased in numbers since it was introduced and the extent of its spread, it is evident that its soil and food requirements as well as needed conditions of moisture and temperature have been met in a manner most satisfactory for the development of the insect. It is probable that soils which are neutral or slightly acid in reaction and an open campestral country, abundant in permanent sod lands and supporting a rich growth of mesophytic vegetation, is most satisfactory for the development of the Japanese beetle.

The insect has been found to feed on about 200 species of plants in New Jersey. These include practically all the economic crops, although the following are preferred: Apple, quince, peach, sweet cherry, plum, grape, blackberry, clover, soybean, and corn; the shade trees attacked include linden, birch, oak, elm, sassafras, horse-chestnut, and willow; ornamental shrubs, particularly althaea and rose, flowers of all kinds, and many kinds of weeds, especially smartweed, are also attacked.

The insect in many cases completely defoliates the trees in addition to causing severe damage by feeding on the early

ripening varieties of fruit. In certain areas in New Jersey the loss of the fruit of early apples in 1923 amounted to about 15 per cent of the crop. In addition to the destruction by the adult beetles, the larvae have damaged lawns, pastures, and golf courses through the feeding which they do on the roots of various grasses. Some injury has also been found to occur to strawberries, cabbage, and other plants which have been set in fields heavily infested with the larvae.

The eggs of the Japanese beetle are white, translucent bodies, approximately one-sixteenth inch in diameter. They are deposited in the soil and hatch on an average in about 14 days.

The larva upon emerging from the egg is about one-sixteenth inch long. The larvae feed on living plant roots, as well as on decaying vegetable matter in the soil. During the course of their development they molt twice, becoming full grown, or nearly 1 inch long, about the third or fourth week in September. The winter is passed in the larval stage, and during May they assume what is known as the prepupal form, a semi-inactive condition between the larval and pupal stages. The insect remains in the prepupal stage for about 11 days. The pupal stage lasts for about two weeks and the adult beetles emerge between the 10th and 20th of June.

The adult Japanese beetle is a brightly colored insect, varying in length from five-sixteenths to seven-sixteenth inch and in width from three-sixteenths to nine thirty-seconds inch. The color is bright, metallic green, except for the greater part of the wing covers, which are coppery brown. The elytra do not entirely cover the abdomen, but expose a row of five

lateral and two posterior marginal spots, composed of white hairs. The legs are colored a dark, metallic, coppery green, varying in tint in different positions.

After emerging from the ground the beetles usually rest for a short period on various low-growing plants, after which they become more active and fly to their various food plants. Beetles have been observed to live on an average for about 44 to 46 days under cage conditions. In many cases the female beetles enter the soil late in the afternoon and deposit several eggs in the ground during the night. Egg-laying extends over a period of three to four weeks and, in all, between 30 and 50 eggs are deposited. It has been found that during the morning the beetles concentrate on low-growing plants, such as smartweed, and as the heat increases during the day they become more active and disperse to the taller plants until early in the afternoon, when they are abundant on the tallest oaks, elms, and maples. After 3 p. m. their flight is toward the ground and lower growing plants. The proportion of females to males is highest between 12 o'clock noon and 2 p. m., and lowest between 6 p. m. and 6 a. m.

The larva forms a cell in the soil slightly larger than its body and feeds on the fine rootlets at the top and bottom of the cell. It usually follows the course of the rootlets until these are consumed before attacking others. Examinations of the material consumed by the larvae have indicated that fresh plant tissues constitute about 64.3 per cent of the material found in their alimentary canal.

Injury to sod land does not usually occur until there are at least 100 or more larvae to each square yard. In some

cases as high as 1,531 larvae have been found to a measured square yard. They usually feed at a depth of one-half to three-fourths inch below the surface.

The injury caused by the feeding of the adult beetles is conspicuous and characteristic, and is comparable with the damage done by native leaf-chafers. Small plants may be defoliated, although on trees the leaves are usually skeletonized, causing them later to turn brown and drop. The beetles prefer to feed on foliage exposed to the direct rays of the sun, and little feeding has been observed in shaded woodlands. Usually the beetles commence to feed on the upper and outer foliage and work downward, and by the time one-half or two-thirds of the foliage on the tree in question has been consumed they leave and congregate on other plants. The beetles are extremely fond of green corn silk and the developing ear. Frequently ears have been noted on which the grains and husk were eaten for more than one-half the length of the cob.

The feeding habits of the beetles are variable and have been found to change somewhat from year to year. Some orchards which are heavily infested early in the season later become entirely free from the beetles and no further damage may be caused. The insects fly actively on clear, warm days, and there is considerable change in their feeding places from day to day.

The total life cycle of the Japanese beetle is one year, five-sixths of this time being spent in the soil as an egg, larva, or pupa. Having passed the winter in the soil, between 2 and 4 inches below the surface, the larvae pupate during May, and transform to adults between June 10 and June 20. The

beetles are present during a period of four months and are most abundant during July and August. A preference is shown by the females for sod land as a place in which to deposit their eggs; larvae, however, have been found abundant in cultivated fields and orchards. The time of pupation and the average emergence time of the adults are 10 days to two weeks earlier in loam soils than in the pure sand types.

The Japanese beetle has spread outward at a rate of 10 to 15 miles each year. It is believed that the spread to date has been largely due to natural factors, and of these the flight of the adult beetle is the most outstanding natural agency of dispersion. Winds and storms probably play some part in the dispersion of the insects. The movement of infested farm products and soil in which larvae occur is probably the most important means by which the beetle could be carried a long distance. During 1923 more than 32,000 beetles were removed from sweet corn consigned to New York from one New Jersey district. Passing vehicles also afford means of artificial dispersion of the insect, but probably not over as long distances as would be the case in shipments of infested produce.

Since its first appearance in 1916 no climatological condition has arisen which has offered any serious check to the numerical increase of the species.

Certain microorganisms are pathogenic to the larvae of the Japanese beetle. In some cases it has been found that these play a role in the natural control of the insect. A few species of fungi have been discovered which attack the larvae of the Japanese beetle.

Several species of insects parasitic on the Japanese beetle in Japan have been imported for the purpose of establishing them in this country. One species (<u>Centeter cinerea</u> Ald.) was imported and released during the seasons of 1922 and 1923. In 1924 beetles were found over an area of approximately 12 square miles which had been parasitized by this introduced parasite. A species of dexiid (<u>Prosena siberita</u> Fabr.) which is parasitic on the larvae of the Japanese beetle has been imported in large numbers, but no data have been collected as yet that would indicate whether it will become successfully established in New Jersey. Several species of Tiphia are being imported in small numbers, and attempts were made without success to introduce the Scolia wasp (<u>Scolia manilae</u> Ashmead) and the moth lacewing (<u>Ithone fusca</u> Newm.). Several species of Carabidae (ground-beetles) have been found to feed on the larvae of the Japanese beetle, and, to some extent, the larvae of certain species of Tabanidae (horse-flies). At the present time, however, there is no evidence of any decided increase in the numbers of various native predacious insects.

It was found that the beetles and the grubs form a portion of the diet of several species of birds, but not to such an extent as to offer any serious check to the multiplucation of the insects.

Following the discovery of the insect in New Jersey efforts were made to eradicate it but these were unsuccessful and were eventually given up. Quarantines have been maintained for several years past restricting the movement of nursery stock as well as the movement of farm produce. A

scouting force is maintained during the summer, which operates over the eastern part of the United States in order to determine the spread of the insect from year to year.

A large amount of work has been done for the purpose of discovering methods of control of the larvae where they occur in sodlands or in the soil about the roots of various types of plants intended for shipment outside the regulated area. A practical means of destroying the larvae in golf greens has been devised, consisting of treating the soil with a dilute solution of carbon-disulfide emulsion. The emulsion is prepared by mixing 1 part by volume of cold-water-soluble resin-fishoil soap, 3 parts of water, and 10 parts of carbon disulfide. The soap and water are mixed in a churn or ice-cream freezer until an even mixture is obtained, then the carbon disulfide is added and emulsified. One quart of the emulsion thus obtained is stirred into 50 gallons of water and the resulting mixture is applied at the rate of 3 pints to each square foot of turf. Various methods have been worked out for the destruction of the insect where it occurs in the soil about the roots of nursery stock. Most of these are based on the use of carbon-disulfide emulsion and an emulsion of wormseed oil applied in dilute form to the soil.

It was found during the early experimental work that the beetles were repelled by the presence of arsenate of lead on the foliage of plants. Advantage was taken of this fact, and many growers have successfully protected their plants through the application of this material in fairly large quantities. In order to prolong the stay of the spray material on the foliage, as well as to increase the percentage of mortality

obatined, mixtures of arsenate-of-lead paste were developed, containing stickers and spreaders of certain types, which have given excellent results. Not only has the killing obtained been greater in many cases but the spreading and sticking qualities of the spraying mixture have been greatly improved. At the present time these mixtures of arsenate of lead are the most promising insecticides for use against the adult beetle.

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